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Estimation of Global Solar Radiation Using Gopinathan and Rietveld Model for Putrajaya, Malaysia.

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Abstract

Solar radiation data plays a vital role in the design and implementation of any solar energy related project. Renewable energy engineers and scientists, always employ solar radiation data of the area under consideration for effective discharge of their duties. For the areas where the measured data is not available, the most common way of obtaining the data is by calculating with the appropriate regression model. This study, estimated the global solar radiation of Putrajaya (latitude, 2.9264°N, longitude, 101.6964°E) Malaysia. In the estimation, two sunshine based empirical models (Gopinathan and Rietveld) were considered, the data used was obtained through simulation from the satellite using Meteonorm software package 7.1.3. The calculated and the simulated values were compared. To determine the accuracy of the models, three commonly used statistical error methods were employed, root mean square error(RMSE), mean bias error(MBE), and R^2which is the coefficient of determinant. From the result, it was observed that only Gopinathan model that is fit for the estimation of global solar radiation in Putrajaya with a coefficient of determinant of 0.9849, while Rietveld model poorly performed with R^2 of -7.5325

Keywords: Global solar radiation, sunshine duration, simulation, empirical model

1. Introduction

Malaysia a developing country located at (2°30'N and 112°30'E) Southeast Asia, drives its energy from the conventional fossil fuels [1]. These products amounted to be 92.8% of its energy sources in 2012, and based on the forecast made by Economic planning unit, by 2030 there will be an increase in energy demand by 5.3% annually [15]. However, this projection included only minimal amount of renewable energy sources. Malaysia is currently experiencing an economic growth and as a result, they have been an increase in energy consumption over the years. Recently in Malaysia, they have been an increase in the use of solar energy for electricity generation and for water pumping in rural areas. However, for effective implementation of any solar power system solar radiation data at a place of interest is essential. The best-known way of obtaining solar radiation data is through the installation of Pyranometers at a given place, but due to high cost of installation and maintenance it is not usually found in many developing countries [13]. For the fact that solar radiation data plays an important role in building an integrated solar power system, but this data is not readily available in many developing countries. Therefore, in such regions where the measured solar radiation data is not available, the common way of estimating solar radiation data is by using other Meteorological data parameters that are readily available [11].

Over the years, different researchers around the world have tried to develop an empirical model that could be used for the estimation of global solar radiation using different Meteorological parameters as, the relative humidity, Temperature, Sunshine duration and cloudiness [7]. Among all the above mentioned Meteorological parameters, the most commonly used and readily available is the sunshine duration. Atmospheric conditions and geographical location are the determining factors of the amount of solar radiation for a given region. Therefore, since the amount of solar radiation falling on the earth surface is affected by climatic and geography of a place, evaluating the amount of solar radiation of a given region is of paramount importance.

Putrajaya in Malaysia is blessed with untapped solar radiation resources throughout the year, but lack meteorological station were the measured global solar radiation data could be obtained. However, other Meteorological parameters like sunshine duration is readily available at the nearby Meteorological stations.

1.1. Background

Throughout the history of mankind solar radiation has been used in various ways as a renewable energy resource. Different solar radiation technologies were applied form of drying, heating, and warming by the ancient people (solar architecture and technology, 1980). The first mechanical solar powered engine was developed in the 19thcentury using a concentrated solar radiation [3]. Becquere in the year 1839 made the first discovery of photovoltaic effect which pioneered the world to the first production of photovoltaic cell in the 1950s which gave a clear mind-set on the use of solar radiation for electricity generation [9]. The world today has various kinds of solar technologies in application.

The world is faced with the challenges of increase in concentration of Co_2 emissions in the atmosphere, global warming, possible shortage of fossil fuel, and the environmental pollution resulting from burning of fossil fuel. To meet the energy demand of the people and save the environment, the world is forced to look for a clean and abundant energy source which is solar energy.

The sun at the Temperature of about 5700k can radiates a power of approximately $1.6\times10^7 w/m^2$, but due to some climatic factors not all the energy radiated reaches the earth surface [14]. The extraterrestrial solar radiation reaching the earth top atmosphere which called the solar constant I_{sc} with a value of $1367 w/m^2$[8]. Most of the solar radiation from the sun are either deflected of absorbed by some certain gases and water vapour present in the atmosphere, of all the total energy from the sun only 50% of it reaches the earth atmosphere.

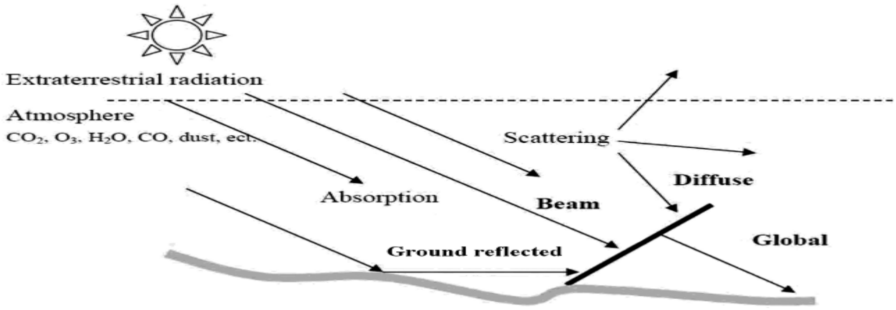

Fig 1. Components of Solar radiation [13]

Therefore, the amount of sunlight reaching the earth surface is enough to meet the total global annual energy demand [4]. The earth surface receives the largest portion of energy from the sun with an equivalent amount of 10,000 times the annual global energy demand [12]. Taking on the average, annual solar radiation received on the earth surface is about 1,700kw/m^2[12].

To design an effective solar energy conversion system, a proper knowledge on solar radiation of a place on the earth surface at a given period is of great importance.

1.2. Global solar radiation data

The solar radiation data provide an information on the total amount of the energy from the sun that falls on the surface of the earth at a location within a given period [28]. This data provides the values of energy received from the sun per unit area at a given location. The availability of solar radiation data is a prime mover in the design of any solar energy system. Presently, there are only two methods of obtaining the amount of solar radiation falling on the earth surface [29]. The use of a measuring instrument (direct method) and by using empirical models and other Meteorological parameters that are readily available.

The direct method of obtaining solar radiation data is further divided into two

1. Using ground mounted instrument like pyranometers and
2. Using satellite

Under good and adequate maintenance, Pyranometers gives the most accurate and reliable solar radiation data of a place at a given period. The use of empirical models in the estimation of global solar radiation is of great importance, since Meteorological stations are mostly not available in many parts of the world due to high cost of installation and maintenance. Therefore, new empirical models are continually suggested and improving the already existing once.

1.3. Global solar radiation models

Engineers and scientists around the world have developed empirical models that could be used for the estimation of global solar radiation from different meteorological parameters. The availability of meteorological data is the determining factor type of empirical model to be used for the estimation of global solar radiation of a place [2]. Therefore, it is important to select the most appropriate model. Below are the classifications of empirical models based on input data.

1. Cloud based models
2. Sunshine based models
3. Temperature based models
4. Other meteorological data based models

Among all the types of models mentioned above, the most commonly used is the sunshine based, cloud based, and the Temperature based models. The three mentioned meteorological parameters can precisely and easy be obtained. [2], carried out a review of global solar radiation estimation models and their meteorological parameters presented in Table 1. below.

Table 1. Model type and their meteorological parameters

Model Type	Quantity
Sunshine based	35
Temperature based	16
Cloud based	6
Other meteorological data	21

From the Table 1 above it can be observed that, the most widely applied parameter in the estimation of the global solar radiation is the sunshine duration. The reason is it can be easily and cheaply obtained without the use of any complex equipment. [7], Presented a linear and quadratic form of global solar radiation estimation models using the monthly mean sunshine hour for Ranchi India a tropical location. In their findings, the quadratic models gave better estimation as compared with that of the linear models. [30], Correlated seven different empirical models, to evaluate the performance of the selected models, five different statistical methods were used. It was suggested that the models that gave the best result could be used for the estimation of global solar radiation in the province of Turkey. [31], Compared various empirical models based on the Angstrom-prescotte model using the monthly average sunshine hour, to test the performance of the models three statistical error test methods were used. They concluded that the models that were selected gave an accurate estimation for Ranchi India. [11], Classified various global solar irradiance estimation models into three categories based on selected geographical locations. They tested the effectiveness and limitations of the models using statistical methods, among all the considered models, the linear models that were based on Angstrom Prescotte model gave an estimation like that of the measured data. [1], examined various empirical models using a daily sunshine hour obtained from Sarawak State Malaysia. Six different models were compared but none of models showed a similar characteristic, a new model was introduced based on the obtained data and was tested using two statistical test methods, the newly introduced model gave a better prediction of the global solar irradiance in all the three selected regions from Sarawak State. It was suggested that the newly developed model could be used in any part of Malaysia with similar climatic condition. [32], suggested a new empirical relation for the prediction of average monthly global solar radiation based on the correlation of Rietveld, Benson et al., and Ogelman et al. The newly suggested Akinoglu and Ecevit gave a better estimation of the global solar radiation. [33], estimated the global solar radiation using the quadratic form of Angstrom-Prescotte model and was compared with those developed for Nigeria. The estimated values showed a relationship between index of clearness and the relative sunshine with the quadratic models depending on the climate of the area. In their study, they concluded that the isotropic model can be used to predict the global solar radiation on a tilted surface in Nigeria and any region with similar climatic conditions. [34], examined some of the existing Meteorological data measurements of the global solar radiation for Italy. To determine where errors were made during the measurement using Angstrom-Black linear relation. In the result, a relative error of 10% in the measured Meteorological data for Italy was observed. [35], Predicted the global solar irradiance using monthly mean sunshine duration. To establish the accuracy of the models, four error statistical test methods were employed. The calculate and the measured data were compared. They concluded that all the selected models gave a better estimation. They suggested that the models could be used for the prediction global solar radiation in the coastal areas of Malaysia. [36] Made a comparative analysis of various empirical models using the measured data and the estimated global solar radiation on a horizontal surface for 52 different cities around the world. To compare the percentage errors in the obtained data and the estimated values, four statistical error test methods were used. It was obtained that Halawani and Rehman model gave an acceptable estimation with a very low percentage error. [37], Suggested a new empirical model for the prediction of global solar irradiance on a horizontal surface for locations that falls within the latitude of 60°N and 70°N. The effectiveness of the model was tested using statistical methods and was compared with other established model but the newly developed Gopinathan model gave an accurate result. [38], Used a sunshine hour duration to evaluate the global solar radiation in Nairobi Kenya, using different solar empirical relations based on Angstrom-Prescotte model. To test the effectiveness of the models under consideration, three statistical methods were employed. They concluded that all the models used in the estimation when compared, only Akinoglu and Ecevit model gave the best estimation. [39], a final year project report, used Angstrom- Prescotte model to evaluate the global solar radiation of Putrajaya with only daily sunshine hour and hourly solar radiation. In his report, he suggested that the model could be used for a feasibility study on global solar radiation in Putrajaya, Malaysia. [6], In their study presented a new model that could be used in predicting direct and diffuse solar radiation for a clear sky. The calculated values obtained from the newly proposed model was compared with the measured meteorological data in Morocco. The result obtained using the proposed model reviled that the model could be used to predict global solar radiation throughout the seasons of the year for the area under consideration by using the geographical information of the area. [19], developed a new mathematical computer based model that could be used to predict global solar radiation using hourly sunshine duration as an input data. To evaluate the performance of the newly developed model, the predicted and the measured data was compared using two different statistical tests methods. They concluded the newly proposed model could be used for the prediction of global solar insolation of the area under consideration. [2], made a review of global solar radiation estimation models and classifying them based on the type of meteorological data. To establish the effectiveness of the selected models, they employed various statistical test methods. In their findings, they found out El-Metwally model gave the most accurate solar radiation value.

Review of sunshine-based solar radiation estimation models by country

Model no.	Regression equation	Country	References
1	$\frac{H}{H_o} = 0.177+0.692(\frac{S}{S_o})$	Italy	[16]
2	$\frac{H}{H_o} = 0.174+0.615(\frac{S}{S_o})$	Jordan	[17]
4	$\frac{H}{H_o} = 0.2281+0.5093(\frac{S}{S_o})$	India	[18]
5	$\frac{H}{H_o} = 0.14+0.57(\frac{S}{S_o})$	U.S.A.	[26]
6	$\frac{H}{H_o} = 0.0.335+0.367(\frac{S}{S_o})$	Pakistan	[20]
7	$\frac{H}{H_o} = 0.2223+0.6529(\frac{S}{S_o})$	China	[21]
8	$\frac{H}{H_o} = 0.215+0.527(\frac{S}{S_o})$	Libya	[23]
9	$\frac{H}{H_o} = -2.81+3.78(\frac{S}{S_o})$	Saudi A.	[27]
10	$\frac{H}{H_o} = 0.1538+0.7874(\frac{S}{S_o})$	Italy	[19]
11	$\frac{H}{H_o} = 0.176+0.563(\frac{S}{S_o})$	China	[24]
12	$\frac{H}{H_o} = 0.23+0.38(\frac{S}{S_o})$	Nigeria	[25]
13	$\frac{H}{H_o} = 0.1332+0.6471(\frac{S}{S_o})$	China	[24]
14	$\frac{H}{H_o} = 0.309+0.368(\frac{S}{S_o})$	Algeria	[23]

1.4. Aims and objectives

This study focuses on providing information on the global solar insolation falling on the horizontal surface in Putrajaya Malaysia through empirical relationship procedures. Firstly, by making a review of some models and their related parameters as used by different researchers, then selecting the most appropriate empirical model based on the available meteorological data, estimating the global solar radiation of Putrajaya, comparing of simulated and calculated values, and finally evaluating the performance of the models through statistical error test methods.

2. Materials and methods

The parameters used for this study was 2016 monthly average sunshine duration and monthly average global solar radiation. The parameters were obtained from the nearest meteorological station in Kuala Lumpur via satellite through simulation Meteonorm software package 7.1.3. Each day of the month was taken from the first of January to December 31st for the evaluation. To calculate for the unknown parameters, the declination angle and the hour angle were calculated first using equations (1) and (2)[5].

$\delta = 23.45\sin[360/365(284+n)]$ (1)

$\omega = \cos^{-1}(-\tan\varphi\tan\delta)$ (2)

Where, δ is the declination angle in (degree), n is the number of days, ω is the hour angle in (degrees), and φ latitude of the area under consideration. From the declination and hour angle s obtained, the value for extraterrestrial solar radiation $H_o$on the horizontal surface was calculated via a relationship in equation (3)[5],.

$$H_o = \frac{24}{\pi} I_{sc}\,[1+0.033\cos(\frac{2\pi n}{365})]\,[\sin\omega\cos\varphi\cos\delta + \omega\sin\varphi\sin\delta] \quad (3)$$

Where, I_{sc} is the solar constant with a value of (1367w/m^2), then calculating the maximum possible sunshine duration using equation (4) below

$S_o = 2/15*\omega$ (4)

Since the simulated parameters were monthly average, the monthly average values of the calculated was taken. To determine the global solar radiation for Putrajaya, two sunshine based empirical models were employed, (Gopinathan and Rietveld) respectively using the relations below.

$$a = -0.309 + 0.539\cos\varphi - 0.0693h + 0.290(\frac{s}{s_o}) \quad (5)$$

$$b = 1.527 - 1.027\cos\varphi + 0.096h - 0.359\left(\frac{s}{s_o}\right) \quad (6)$$

[6], link a relationship between regression constant **a** and **b** in equation (5) and (6) above with sunshine duration, latitude, and elevation. [10], on the other hand, established a relationship between regression constant **a** and **b**in equation (7) and (8) with sunshine duration.

$$a = 0.10 + 0.24\left(\frac{s}{s_o}\right) \quad (7)$$

$$b = 0.38 + 0.08(\frac{s}{s_o}) \quad (8)$$

Where, *S*is the sunshine duration simulated

To finally calculate the global solar radiation for Putrajaya, the equation linking all the calculated and simulated parameters using the correlation in (9).

$$H_{gcal.} = H_o\left[a + b\left(\frac{s}{s_o}\right)\right] \quad (9)$$

Where $H_{gcal.}$ is the calculated global solar radiation and to calculate for the clearness index, the equation below was used

$K_T = H_{gcal.}/H_o$ (10)

2.3. Models accuracy

To determine the accuracy of the selected models, three commonly used statistical methods were employed, root mean square error(RMSE), mean bias error(MBE), and R^2 which is the coefficient of determinant. Generally, low root mean square error indicates good result, and as well high mean bias error indicates over estimation and when negative shows underestimation of the values. For the coefficient of determinant R^2 when the value is closer to one, the more precise the result. Below are the definitions of the statistical methods used in the study.

$$RMSE = \sqrt{\sum (Xi - Yi)^2 / n} \quad (11)$$

$$MBE = \sum (Xi - Yi)/n \quad (12)$$

The percentage errors were determined using equation (13) and (14) below

$$\%RMSE = \frac{RMSE}{Y_m} \times 100 \quad (13)$$

$$\%RMSE = \frac{MBE}{Y_m} \times 100 \quad (14)$$

$$R^2 = 1 - \frac{\sum (Xi - Yi)^2}{Y_i} \quad (15)$$

Where Xi is referred to the i^th value calculated solar radiation, Yi is the i^th value of simulated solar radiation, Y_m mean simulated values, R^2 is the coefficient of determinant and n is the number of data set points

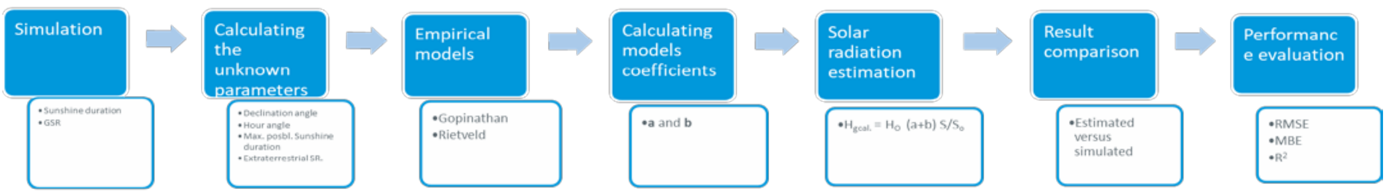

Fig 2. Solar radiation estimation methods

3. Results

Table 2. Monthly global solar radiation related parameters for Putrajaya Malaysia.

Months	S (Hrs)	$H_g$simulated (kwh/m^2/mon.)	H_oExtraterrl. (kwh/m^2/mon	S_o (Hrs)	δ (degrees)	ω (radians)	ω (degrees)
January	6	78	100.44	11.843	-20.085	1.551	88.87
February	6.9	68	103.70	11.877	-13.323	1.559	89.09
March	6.8	93	108.29	12.377	-2.259	1.619	92.78
April	6.7	82	101.74	12.012	9.856	1.579	90.09
May	6.8	80	96.25	12.133	19.036	1.588	91

June	6.5	78	92.91	12.163	23.077	1.593	91.24
July	6.5	79	94.31	12.147	20.933	1.59	91.1
August	6.15	82	99.20	12.088	12.967	1.582	90.66
September	5.8	69	103.24	12.003	1.596	1.572	90.07
October	5.7	77	103.38	11.928	-10.208	1.562	89.46
November	5.1	71	100.67	11.863	-19.275	1.552	88.96
December	5.2	69	103.93	11.583	-3.293	1.517	86.92

Table 3a. Summary of monthly average regression constant, clearness index, and sunshine duration ratio (Gopinathan model)

Months	A	B	$H_{g\ cal.}$	$H_{g\ sim.}$ / $H_{g\ cal.}$	$H_{g\ cal.}$ /H_o	S/S_o
January	1.1319	0.2919	85.8172	0.9089	0.8544	0.5063
February	1.3929	-0.0311	97.4462	0.9235	0.9396	0.5808
March	1.3639	0.0047	100.7917	0.7937	0.9307	0.5496
April	1.3349	0.0406	93.7713	0.8638	0.9216	0.5577
May	1.3639	0.0047	89.5884	1.0045	0.9307	0.5604
June	1.2769	0.1124	83.9155	0.9175	0.9031	0.5343
July	1.2769	0.1124	85.1763	0.9274	0.9031	0.5351
August	1.1754	0.2380	86.2409	0.8348	0.8693	0.5087
September	1.0739	0.3637	86.0905	1.0221	0.8338	0.4829
October	1.0449	0.3996	85.1324	0.9514	0.8234	0.4778
November	0.8709	0.6150	76.2956	0.9043	0.7578	0.4299
December	0.8999	0.5791	79.9424	0.9757	0.7691	0.4486

Table 3b. Summary of monthly average regression constant, clearness index, and sunshine duration (Rietveld model)

Months	A	B	$H_{g\ cal.}$	$H_{g\ sim.}$ / $H_{g\ cal.}$	$H_{g\ cal.}$ /H_o	S/S_o
January	2.04	2.76	289.28	0.2696	2.880	0.5063
February	2.346	3.174	394.98	0.2278	3.808	0.5808
March	2.312	3.128	400.59	0.1997	3.699	0.5496
April	2.278	3.082	365.36	0.2216	3.591	0.5577
May	2.312	3.128	356.06	0.2527	3.699	0.5604
June	2.21	2.99	314.05	0.2451	3.380	0.5343
July	2.21	2.99	318.77	0.2478	3.380	0.5351
August	2.091	2.829	300.16	0.2398	3.025	0.5087
September	1.972	2.668	277.83	0.3167	2.691	0.4829
October	1.938	2.622	268.72	0.3014	2.599	0.4778
November	1.734	2.346	209.47	0.3293	2.080	0.4299
December	1.768	2.392	224.83	0.3469	2.163	0.4486

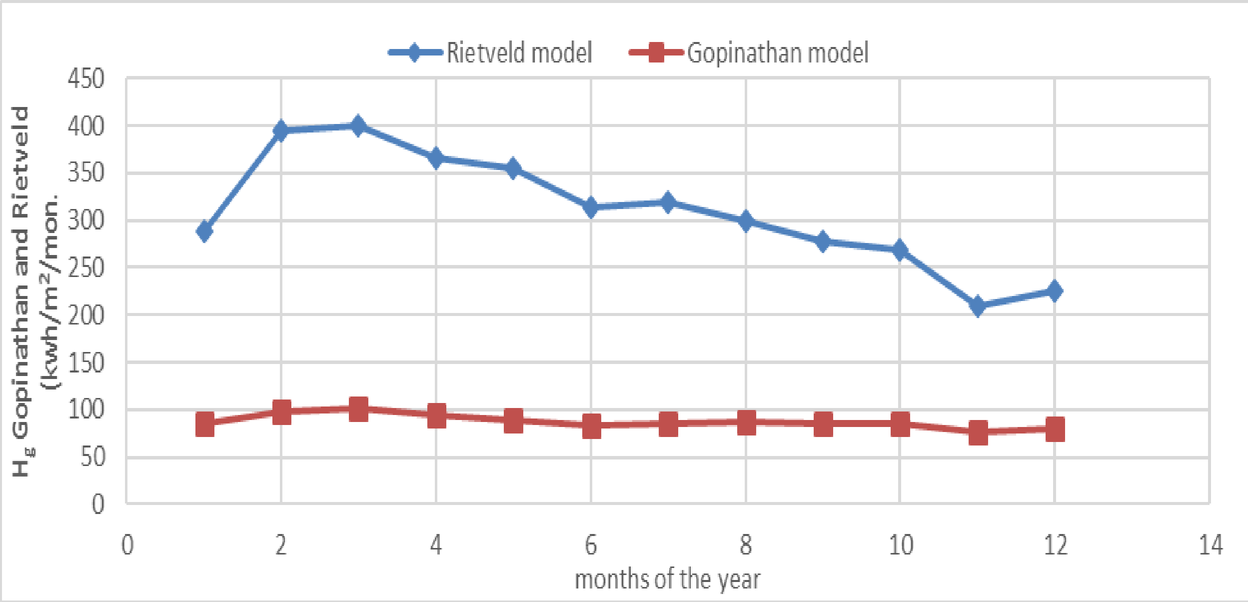

Fig.3 Graph of GSR obtained by the two models

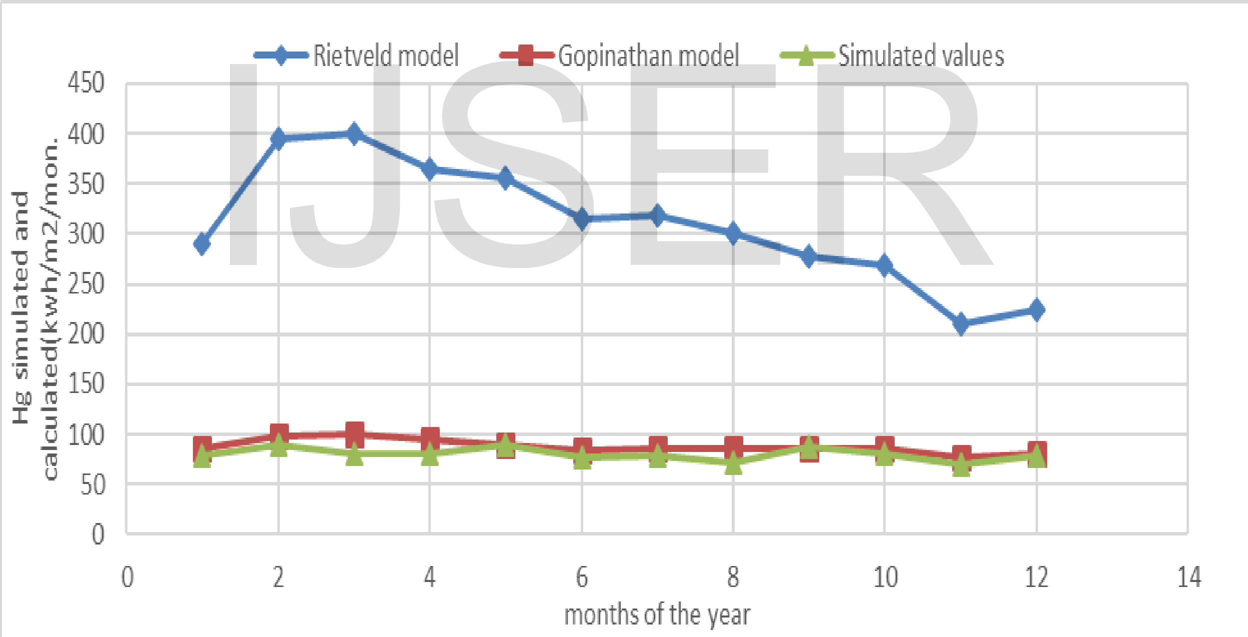

Fig 4. Graph of the simulated GSR against modelled GSR

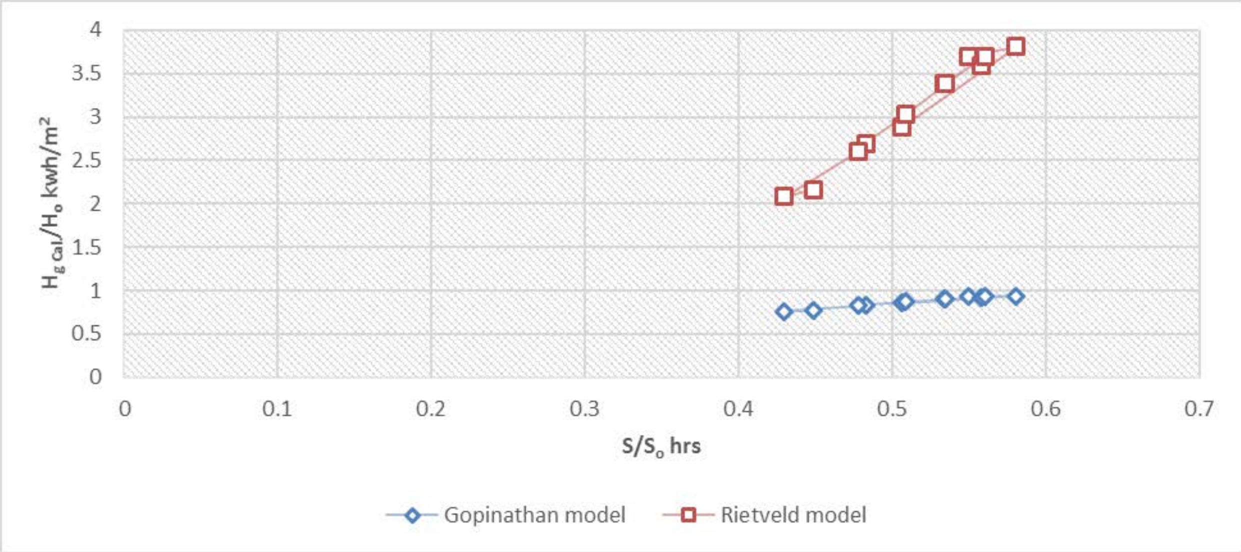

Fig 5. Variation in clearness of index with Sunshine duration for Putrajaya

Table 4. Summary of monthly average statistical parameters and regression constant

Models	**A**	**B**	**RMSE**	**MBE**	**%RMSE**	**%MBE**	**R^2**
Gopinathan	1.1839	0.2276	2.2095	0.6550	2.7533	0.7548	0.9849
Rietveld	2.1009	2.8420	19.1469	19.1469	0.2258	0.2385	-7.5325

4. Discussions

To calculate for the regression constant of each of the models selected, geographical coordinate and other meteorological parameters were taken into consideration. Model effectiveness is an important factor to consider when estimating global solar radiation for an area. A model is said to have performed well or reliable if the value of coefficient of determinant R^2 is closer to 1. Therefore, the monthly average coefficient of determinant R^2 for both the selected model were calculated as presented in Table 4. Gopinathan model gave the value of R^2 to be 0.9849 indicating a very excellent relationship with the monthly average solar radiation and other meteorological data, while Rietveld model on the other hand performed very poor giving the value of R^2 to be -7.5325. For each of the selected models, the solar radiation fraction H_{gCal} ./H_o, and sunshine duration S/S_o was calculated as presented in Tables 3a and 3b.To evaluate the performance of the selected models, statistical methods were employed, root mean square error(RMSE), mean bias error(MBE), and their respective percentages as presented in Table 4. Low root mean square error indicates good result, and as well high mean bias error indicates over estimation and when negative shows underestimation of the values.

From all the statistical analysis carried out, monthly mean RMSE for Gopinathan was found to be 2.2095kwh/m$^{2/}$/mon. and MBE to be 0.655kwh/m^2/mon., while the %RMSE is 2.733 and %MBE is 0.7588 showing a good relationship with the solar radiation estimation model. For Rietveld model, the values for RMSE and MBE was found to be the same at 19.1469kwh/m^2/mon. while the %RMSE and %MBE was found to be 0.2258 and 0.2385 respectively. Though, the monthly mean percentage the that was found in Rietveld model is low, but it poorly performed in the value of coefficient of determinant R^2. To know if any relationship between the models exist in the estimation of global solar radiation for Putrajaya, a graph GSR obtained by each model was plotted against the months of the year shown in Fig.3. It was observed that, the models have no any relationship throughout the months of the year. The simulated values and the modelled values, was also plotted as presented in Fig. 4. The Rietveld model was still observed not to have any similarities with the simulated value, Gopinathan model on the other hand has indicated a strong relationship with the simulated global solar radiation values except for the months of March, April, and August with the highest values of 100.7917kwh/m^2/mon., 93.7713kwh/m^2/mon., and 86.2409kwh/m^2/mon. which also correspond with the simulated highest values to be 93kwh/m^2/mon., 82kwh/m^2/mon., and 82kwh/m^2/mon. Table 3a. Considering the clearness index obtained by Gopinathan model, the lowest value for $H_{gCal}/H_o$to be 0.7578kwh/m^2/mon. and S/S_o to be 0.4299 corresponding with the lowest H_{gCal}76.2656kwh/m^2/mon. in the month of November. For the simulated, the lowest the clearness index $H_{gSim.}/H_o$ and the H_{gsim} corresponded with that of Gopinathan in the same month of November having the values of 0.9043kwh/m^2/mon and 71kwh/m^2/mon. This, indicate a strong relationship between Gopinathan model and the simulated GSR. The values of clearness index obtained by Rietveld model, have neither indicated any relationship with the simulated or the Gopinathan model as presented in Fig 5.

5. Conclusions

The solar radiation data gives an information on the total amount of the energy from the sun that falls on the surface of the earth at a location within a given period. This data provides the values of energy received from the sun per unit area at a given location. The availability of solar radiation data is a prime mover in the design of any solar energy system. The study estimated the global solar radiation of Putrajaya using two sunshine based models, Gopinathan and Rietveld model. The values obtained by the models were compared with the simulated data, statistically tested to evaluate their performances, and established a correlation for Putrajaya using Gopinathan model. when compared with the simulated values, only Gopinathan model indicated a strong relationship while the Rietveld model has overestimated the global solar radiation for Putrajaya. On the bases of statistical test, Gopinathan model also performed excellently by giving the value coefficient of determinant R^2 to be 0.9849, while Rietveld model has failed by giving the value of coefficient of determinant R^2 to be -7.5325. Therefore, Gopinathan model gave the most accurate result which makes the model to be reliably used for the estimation of global solar radiation in Putrajaya.

6.Recommendation

The solar radiation data provide an information on the total amount of the energy from the sun that falls on the surface of the earth at a location within a given period. This data provides the values of energy received from the sun per unit area at a given location.
This study was basically focused on the sunshine-based models for the estimation of global solar radiation for Putrajaya Malaysia and any other location with similar climatic conditions. However, they are many places exist where solar radiation data is not readily available. Therefore, it is important to consider other readily available meteorological data

parameters like; Relative humidity, air temperature, dewpoint temperature, and soil temperature for the estimation of global solar radiation. Thus, it could be concluded that a given area or a location, correlation will be suitable to estimate the monthly average daily solar radiation. Therefore, future researchers should expand their research to using other available meteorological data in other to make solar radiation estimation more accurate for Putrajaya Malaysia

6. References

[1] A.Q. Jakhrani, A.K. Othman, A.R.H. Rigit and S.R. Samo (2011). Model for Estimation of Global Solar Radiation in Sarawak, Malaysia.World Applied Sciences Journal 14 (*Special Issue of Food and Environment*), pp-83-90.

[2] Besharat, F., Dehghan, A. and Faghih, A. (2013). Empirical models for estimating global solar radiation: A review and case study. *Renewable and Sustainable Energy Reviews*, 21, pp.798-821.

[3] Butti, K. and Perlin, J. (1981). *A golden thread*. 1st ed. London: M. Boyars.

[4] Boer, R., 2001. Technologies and prospects for photochemical conversion and storage of solar energy: A survey of the state-of-the-art. ECN-C--01-029 ECN energy efficiency in industry, pp.7-9

[5] Duffie, J. A. and Beckman, W. A., 1991. Solar Engineering of Thermal Processes, 2nd edition, New York: Wiley Interscience.

[6] Gopinathan, K. (1988)[1]. A general formula for computing the coefficients of the correlation connecting global solar radiation to sunshine duration. *Solar Energy*, 41(6), pp.499-502.

[7] Namrata, K., Sharma, S. and Saksena, S. (2013)[2]. Comparison of Different Models for Estimation of Global Solar Radiation in Jharkhand (India) Region. *Smart Grid and Renewable Energy*, 04(04), pp.348-352.

[8] NREL (National Renewable Energy Laboratory Solar Spectra): Standard Air Mass Zero. http://rredc.nrel.gov/solar/spectra/am0/ASTM2000.html/. Accessed on October 7, 2013

[9] Oak Ridge Institute for Science and Educ. (2006). *U.S. Department of Energy Global Change Fellowships, 1991-2006*. 1st ed. Washington, D.C.: United States. Dept. of Energy.

[10] Rietveld, M. (1978). A new method for estimating the regression coefficients in the formula relating solar radiation to sunshine. *Agricultural Meteorology*, 19(2-3), pp.243-252.

[11] Tolabi H., Moradi, M. and Ayob, S. (2014). A review on classification and comparison of different models in solar radiation estimation. *International Journal of Energy Research*, 38(6), pp.689-701.

[12] Patel, M. (2006). *Wind and Solar Power Systems: Design, Analysis, and Operation*. 2nd ed.

[13] Badescu, V. (2008). *Modeling solar radiation at the earth's surface*. Berlin: Springer.

[14] Anon, (2017). [online] Available at: http://esa21.kennesaw.edu/activities/solar/solaractivity [Accessed 30 Jun. 2017].

[15] EPU. (2017). *Malaysia economic planning unit on energy 2012 - Google Search*. [online] Available at: http://www.google.com/search?q=Malaysia+economic+planing+unit+on+energy+2012&ie=utf-8&oe=utf-8&client=firefox-b-ab [Accessed 1 Jul. 2017].

[16] Jain, P. (1986). Global irradiation estimation for Italian locations. *Solar & Wind Technology*, 3(4), pp.323-328.

[17] Alsaad, M. (1990). Characteristic distribution of global solar radiation for Amman, Jordan. *Solar & Wind Technology*, 7(2-3), pp.261-266.

[18] Katiyar, A. and Pandey, C. (2010). Simple correlation for estimating the global solar radiation on horizontal surfaces in India. *Energy*, 35(12), pp.5043-5048.

[19] Jain, S. and Jain, P. (1988). A comparison of the Angstrom-type correlations and the estimation of monthly average daily global irradiation. *Solar Energy*, 40(2), pp.93-98.

[20] Raja, I. and Twidell, J. (1990). Distribution of global insolation over Pakistan. *Solar Energy*, 44(2), pp.63-71.

[21] Li, H., Ma, W., Lian, Y., Wang, X. and Zhao, L. (2011). Global solar radiation estimation with sunshine duration in Tibet, China. *Renewable Energy*, 36(11), pp.3141-3145.

[22] Said, R., Mansor, M. and Abuain, T. (1998). Estimation of global and diffuse radiation at Tripoli. *Renewable Energy*, 14(1-4), pp.221-227.

[23] Chegaar, M. and Chibani, A. (2001). Global solar radiation estimation in Algeria. *Energy Conversion and Management*, 42(8), pp.967-973.

[24] Rensheng, C., Shihua, L., Ersi, K., Jianping, Y. and Xibin, J. (2006). Estimating daily global radiation using two types of revised models in China. *Energy Conversion and Management*, 47(7-8), pp.865-878.

[25] Akpabio, L., Udoimuk, A., Etuk, S. and Udo, I. (2008). Comparison of Diffuse Solar Radiation Models Using Data for Onne, Nigeria. *Global Journal of Pure and Applied Sciences*, 14(4)

[26] Lewis, G. (1992). An empirical relation for estimating global irradiation for Tennessee, U.S.A. *Energy Conversion and Management*, 33(12), pp.1097-1099.

[27] El-Sebaii, A., Al-Ghamdi, A., Al-Hazmi, F. and Faidah, A. (2009). Estimation of global solar radiation on horizontal surfaces in Jeddah, Saudi Arabia. *Energy Policy*, 37(9), pp.3645-3649.

[28] Oak Ridge Institute for Science and Educ. (2006). *U.S. Department of Energy Global Change Fellowships, 1991-2006*. 1st ed. Washington, D.C.: United States. Dept. of Energy.

[29] Patel, M. (2006). *Wind and Solar Power Systems: Design, Analysis, and Operation*. 2nd ed.

[30] Bakirci, K. (2009). Correlations for estimation of daily global solar radiation with hours of bright sunshine in Turkey. *Energy*, 34(4), pp.485-501.

[31] Namrata, K., Sharma, S. and Saksena, S. (2011)[1]. Comparison of Different Models for Estimation of Global Solar Radiation in Jharkhand (India) Region.*International Journal of Science and Advanced Technology* 2(4), pp-132-137.

[32] Akinoğlu, B. and Ecevit, A. (1990). Construction of a quadratic model using modified Ångstrom coefficients to estimate global solar radiation. *Solar Energy*, 45(2), pp.85-92.

[33] Akpabio, L., Udoimuk, A., Etuk, S. and Udo, I. (2004)[1]. Emperical correlation of global Solar Radiation with meteorological Data for Onne, Nigeria. *Turkish J, Physics, 28:* pp.222-227.

[34] Andretta, A., Bartoli, B., Coluzzi, B., Cuomo, V., Francesca, M. and Serio, C. (1982). Global Solar Radiation Estimation from Relative Sunshine Hours in Italy. *Journal of Applied Meteorology*, 21(10), pp.1377-1384.

[35] Wan Nik, W., Ibrahim, M., Samo, K. and Muzathik, A. (2012). Monthly mean hourly global solar radiation estimation. *Solar Energy*, 86(1), pp.379-387.

[36] Rehman, S. and Halawani, T. (1997). Global solar radiation estimation. *Renewable Energy*, 12(4), pp.369-385.

[37] Gopinathan, K. and Soler, A. (1992)[2]. A sunshine dependent global insolation model for latitudes between 60°N and 70°N. *Renewable Energy*, 2(4-5), pp.401-404.

[38] Onyango, A. and Ongoma, V. (2015). Estimation of mean monthly global solar radiation using sunshine hours for Nairobi City, Kenya. *Journal of Renewable and Sustainable Energy*, 7(5), p.053105

[39] Yew, T.K. (2016). Estimation of global solar radiation in Putrajaya. Master's degree project report. *Department of Renewable Energy Engineering, Heriot-Watt University, Putrajaya, Malaysia.*